Development of Large Strain Actuator Controlled by Hydrogen Pressure for artificial muscle

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ABSTRACT: The large strain actuator controlled by hydrogen pressure for artificial muscle was developed. The actuator was constructed with two kinds of soft rubbers for driving and supporting like bimetals. The $LaNi_5$ hydrogen storage alloy powder was dispersed in the driving rubber. The reversible shape change was by hydrogen absorption and desorption. Large strain was observed on long operation time. The large strain over 2000 ppm was observed at above 10000 s of operation time. The actuator developed shows large shape change as large as that of a typical shape memory alloy.

INTRODUCTION

Shape memory materials can be one of the reliable actuator for artificial muscle. However, it is difficult to apply them for artificial muscle because thermal changes often destroy cellular tissues and hardness of Ti-Ni shape memory alloy is too hard for artificial muscle. Thus, a new type actuator for artificial muscle induced by volume expansion of hydrogen storage alloy was developed. Silicone rubber has been used as parts of human body because of soft material. This actuator was constructed with two kinds of soft rubbers for driving and supporting like bimetals. One of them was a driving rubber with hydrogen storage alloy powder dispersed, and another was pure silicone supporting rubber. This soft actuator using silicone rubber can move variable directions with and without temperature change. The size of driving rubber is controlled by hydrogen pressure. In past study, $LaNi_3Co_2$ hydrogen storage alloy has been proposed for soft catheter (Kim, et al., 2001). Because the volume expansion of $LaNi_3Co_2$ alloy by formation of hydride is as large as 20.5 % at human body temperature (Willems, et al., 1984), therefore big power and displacement can be expected. The soft actuator shows large strain yield by shape change as large as Ti-Ni shape memory alloy (Kim, et al., 2001). On the other hand, $LaNi_5$ alloy shows large volume expansion by formation of hydride is as large as 24 % (Sakai, et al., 1990). Since the volume expansion of $LaNi_5$ alloy generates a high power, plastic deformation of 18-8 stainless steel reaction tube was observed (Yabe, et al. 2003). Therefore, hydrogen storage alloys applied for soft actuator has been expected to become high potential candidates for powerful actuators. In this study, a soft actuator driven by hydrogen storage $LaNi_5$ alloy for artificial muscle has been studied.

EXPERIMENTAL PROCEDURE

$LaNi_5$ hydrogen storage alloys were prepared by arc melting (ACM-DS01, DIAVAC Ltd.) and subsequent annealing for homogenization. The block sample was pulverized by several hydrogen cycles of adsorption and desorption using ultra high purity H_2 gas (7N); the resulting powder was classified to obtain a mean grain size between 45 and 90 μm in diameter. The chemical composition of hydrogen storage alloy powder was analyzed by energy dispersive X-ray spectroscopy (EDS: JSM-6301F, JEOL Ltd.). Hydrogen storage alloy powder (0.65 g) was mixed and dispersed within pure silicone rubber (KE45, Shin-etsu Silicon Ltd., 0.065 g). Pure silicone rubber (B) attached was supporting materials to bend the composite material (Kim, et al., 2001). The sample size of the composite material ($30 \times 5 \times 1.0$ mm^3; length × width × thickness) is shown in Figure 1.

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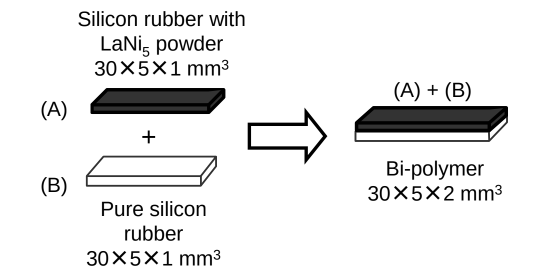

Figure 1. *Schematic diagram of soft actuator preparation.*

Using a reaction bed made of SUS316, the soft actuator was activated using ultra high purity H_2 (7N) of about 30 bar. Activation was performed by the hydrogen absorption for 10 minutes and subsequent evacuation of 10 minutes. The number of the operation cycles was 30 times. An activated bi-polymer was then transported to reaction bed made of glass (See Figure 2). Activation was performed by the hydrogen absorption for 10 minutes and subsequent evacuation of 10 minutes. After evacuation for hydrogen desorption, shape memory effect for 0 ~ 80000 s was monitored by a video recorder (Kim, et al., 2001).

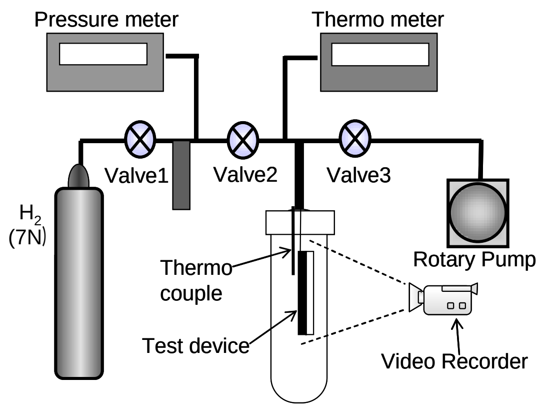

Figure 2. *Schematic diagram of shape change observation system.*

The measurement of the strain of the soft actuator was defined, as shown in Figure 3 and equation (1) to (5). The movable strain (ε) was calculated by equation (1) to (4) using the radius of curvature at the interface (ρ) and a half thickness of sample (η).

$$\varepsilon = \eta / \rho \qquad . (1)$$

$$\rho = (r + d) / 2 \qquad . (2)$$

$$\eta = d / 2 \qquad . (3)$$

Therefore,

$$= d / (2r + d) \qquad . (4)$$

Here, d and r are the thickness of test device and radius of curvature, respectively.

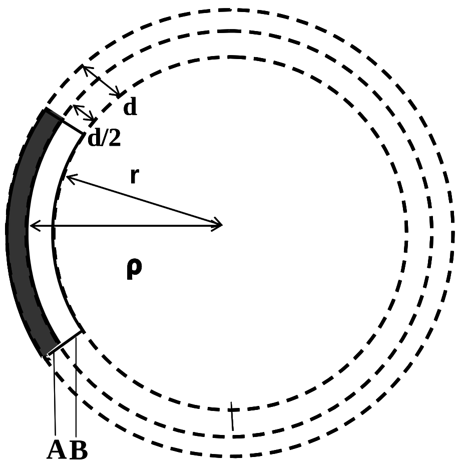

Figure 3. *Schematic diagram for estimation of strain (ε).*

The strain difference ($\Delta\varepsilon$) yielded by shape change of the soft actuator before and after hydrogen gas absorption was defined as equation (5).

$$\Delta\varepsilon = \varepsilon - \varepsilon_0 \qquad (5)$$

Here, ε_0 is initial strain before the first hydrogen absorption in glassy reaction tube.

RESULTS AND DISCUSSIONS

Figure 3 shows photographs of the shape of the soft actuator at different operation times. The large shape changes were observed at long operation time. This soft actuator showed reversible shape change by hydrogen absorption and desorption.

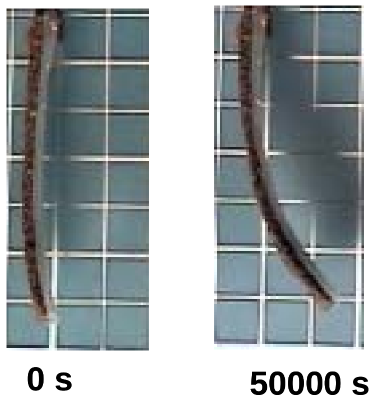

Figure 3. *Photographs of the shape of the bi-polymer on each operation time (0 and 50000 s) after hydrogen absorption at 297.0±1.0 K by applying hydrogen pressure of 2.9±0.5 bar.*

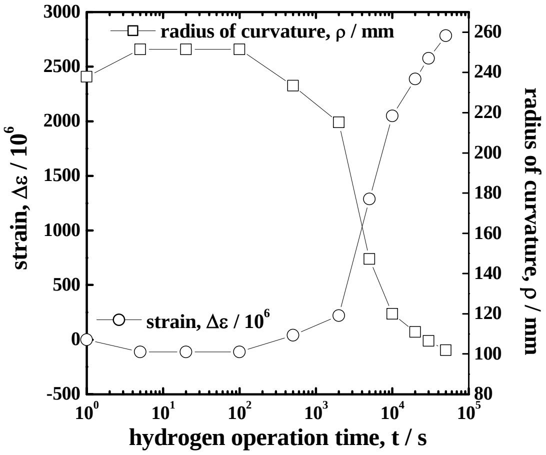

Figure 4*. Relationship between the applied hydrogen operation time (s) and the strain yielded by shape change $\Delta\varepsilon$ (ppm) of hydrogen storage soft actuator, together with relationship between the applied hydrogen operation time (s) and the changing the radius of curvature (mm).*

Figure 4 shows the relationship between the applied hydrogen operation time (*s*) and the strain yielded by shape change $\Delta\varepsilon$ (ppm) of hydrogen storage soft actuator, together with the relationship between the applied hydrogen operation time (*s*) and the changing the radius of curvature (mm). Large strain was found at long hydrogen operation time. On the other hand, the long hydrogen operation time shortened the radius of curvature. The large strain over 2000 ppm was observed at above 10000 s of operation time.

CONCLUSION

In this study, the hydrogen storage alloy dispersed soft actuator showed reversible shape change by hydrogen absorption and desorption. Large strain was found at long hydrogen operation time. The long hydrogen operation time shortened the radius of curvature. The large strain over 2000 ppm was observed at above 10000 s of operation time. The soft actuator shows large shape change as large as that of shape memory alloy.

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REFERENSES

BS. Kim, H. Yabe, H-H. Uchida & Y. Nishi 2001. "Development of a high power shape memory materials using hydrogen storage alloy dispersed in polymer" *Proceedings of 7th Japan International SAMPE Symposium*, 13-16 November 2001, Tokyo, Japan 943-946.

BS. Kim, N. Motai, H. Yabe, H-H. Uchida & Y. Nishi 2001. "Load dependence of shape memory effect of hydrogen storage alloy bi-polymer" *Proceedings of 6th Japan-Korea Joint Symposium on Hydrogen Energy*,18 October 2001, Kanagawa, Japan 189-194.

J.J.G.Willems 1984. "Metal hydride electrodes stability of $LaNi_5$-related compounds" *Phi. J. Res*, 39:1-94.

T. Sakai, K. Oguro, H. Miyamura, N. Kuriyama, A. Kato & H. Ishikawa 1990. "Some factors affecting the cycle lives of $LaNi_5$-based alloy electrodes of hydrogen batteries" *Journal of Less-Common Metals*, 61:193-202.

H. Yabe, T. Honjo, S. Tsubuteishi, H-H. Uchida & Y. Nishi 2003. "Influence of tensile stress on active motion of hydrogen storage alloy film actuator" *Transactions of the Materials Research Society of Japan*, in press.